RESEARCH DEPARTMENT

EFFECTS OF POLARIZATION ON A MEDIUM-FREQUENCY SKY-WAVE SERVICE AT LOW LATITUDES

Report No. G-083

(1962/25)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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1. INTRODUCTION

A satisfactory sky-wave service on medium frequencies by one-hop or two-hop paths becomes possible after dark over distances between about 500 and 3000 km, but one of the two possible modes, namely the extraordinary wave, into which the wave is resolved on entering the ionosphere, is generally much more heavily absorbed than the other mode. Thus the main contribution to the field strength in a m.f. sky-wave service is that due to the stronger ordinary wave. In temperate latitudes the "dip angle" of the Earth's magnetic field is large, e.g. 70° over England, and the polarization of the ordinary wave emerging from the ionosphere tends to be circular, or elliptical with an appreciable component of the electric field in the vertical plane.[1,2] On the other hand, in low latitudes, where the Earth's field is approximately horizontal in a north-south direction, the polarization of the ordinary wave propagated in an east-west direction is closely linear with a horizontal electric field, while that of the extraordinary wave is closely linear with a vertical electric field. Moreover, it appears impracticable to employ other than effectively vertically-polarized aerials at medium frequencies at either the transmitting end or the receiving end. The effect of this is that the amplitude of ordinary wave produced in the ionosphere by a transmitting aerial is very small, and also that the ordinary wave component emerging from the ionosphere will have a very poor degree of coupling with the receiving aerial. As the direction of propagation departs from the magnetic east-west, the ordinary wave polarization will become elliptical with a slight tilt from the horizontal, and finally almost circular as a north-south direction of propagation is approached.

2. EFFECTIVE REFLEXION COEFFICIENT OF ORDINARY RAY

2.1. Idealized Case

Table 1 gives the effective reflexion coefficient for the ordinary ray assuming, as an extreme case, that

(i) The angle of dip is zero (taking the value near the point of reflexion).

(ii) No contribution to the received strength is made by the extraordinary wave or ground wave; i.e., only the ordinary wave reflected in E region is effective.

(iii) A service at a range of about 940 km is considered, corresponding to an angle of incidence in the E layer at 110 km at 75° (or angle of elevation of 15°).

(iv) A vertically polarized aerial is employed at the sending and receiving ends.

(v) The transmitter frequency and the gyro-magnetic frequency are both 1 Mc/s.

(vi) The absorption of the ray below the reflexion point may be neglected.

TABLE 1

Theoretical variation of effective ordinary-wave field strength with vertically-polarized aerials and zero magnetic dip angle

Magnetic bearing of transmitter	Polarization ellipse of electric field: Axial ratio	Polarization ellipse of electric field: Rotation from minor-axis-horizontal position	Effective voltage reflexion coefficient if only ordinary wave present
0°	0·966	0°	0·52
±15° ±165°	0·933	46·0°	0·50
±30° ±150°	0·837	65·9°	0·44
±45° ±135°	0·683	75·5°	0·34
±60° ±120°	0·483	81·5°	0·20
±75° ±105°	0·250	86·0°	0·063
±90°	0	90°	0

2.2. Consideration of More General Cases

In the presence of ionospheric absorption a further factor, largely independent of bearing, has to be applied. The values in the right-hand column of Table 1 will give a good idea of the way in which the effective field strength of the ordinary ray varies with bearing, and may be regarded as giving an effective radiation pattern of the transmitter. The actual field strength for a north-south path at low latitudes will be approximately equal to that for a path of similar length in temperate latitudes.

If the dip angle is not close to zero (assumption (i) above), the minimum of the effective pattern is filled in, and the minimum reflexion coefficient for east-west propagation is approximately $\sin^2 D$ for small angles of dip, D. The more general case will require individual calculation and formulae are given in the Appendix.

The range of the service considered affects the shape of the pattern, but not greatly for oblique paths corresponding to ranges in excess of about 800 km. A change of frequency in the range 800-1200 kc/s has only a slight effect on the ordinary-wave field strength and its variation with bearing. Lower frequencies tend to give slightly lower reflexion coefficients than those in Table 1 for directions close to the east-west direction.

Regarding assumption (ii), it is possible that the extraordinary wave, which will be linearly polarized with the electric field component in a vertical plane for an east-west path, will contribute appreciably in the region near the minima. The contribution is difficult to estimate for a number of reasons, the chief one being that under some conditions the extraordinary wave can penetrate the E region and be reflected from the F region even for ionization densities which rule out paths other than E reflexion for the ordinary wave. Other possibilities are multi-hop paths and sporadic-E reflexions which might also allow significant amounts of energy to be propagated by the extraordinary wave. The frequency and time of day are important factors in determining the strength of both waves. If it is possible to use a horizontally polarized aerial at one end of the path, e.g. at the transmitting end, appreciable coupling loss will occur only at the end employing a vertically polarized aerial, not at both ends of the path as in the case considered above. While there is still, in theory, a heavy loss for a magnetic east-west path and zero dip angle, for any condition not quite approaching this extreme the loss will be less than for the case of two vertically polarized aerials. The attenuation in decibels will be approximately halved but the exact value will depend not only on the dip angle and departure from the east-west direction but also on which end of the path has the vertically polarized aerial.

3. CONCLUSIONS

Theory shows, in the first place, that the principal mode of m.f. propagation, namely the ordinary wave, is subject to a very severe coupling loss for east-west paths at low latitudes when using conventional aerials. Moreover, there is a lack of information on m.f. sky-wave characteristics particularly on the extent to which the extraordinary wave contributes. It appears from theory that, while the non-deviative part of the absorption of the extraordinary wave may be no greater than that of the ordinary wave in the case of east-west propagation, there is likely to be heavy absorption of this wave near the reflexion point. This will be most marked for frequencies close to the gyro-frequency which may be about 1 Mc/s or lower in tropical latitudes. Therefore, it must be a matter of experiment to determine how poor the east-west propagation is, and how consistent it is from night-to-night, in view of the uncertainty of the important modes of propagation of medium frequencies for such a path at low latitudes.

4. REFERENCES

1. Phillips, G.J., "The Influence of the Ionosphere on Medium-Wave Broadcasting", B.B.C. Quarterly, Vol.8, No.1, 1953.

2. Eckersley, T.L. and Millington, G., "The Limiting Polarization of Medium Waves reflected from the Ionosphere", Proceedings of the Physical Society, Vol.51, Part I, p.110, 1939.

5. APPENDIX

The calculation of the effective reflexion coefficient for the ordinary wave is best described in separate stages as follows.

5.1. Propagation Direction Relative to Earth's Magnetic Field and the Orientation of the Ellipse of Polarization of Downcoming Ray

The propagation direction is required in order to determine the ellipticity of polarization. The major axis of the polarization ellipse for the electric field lies in a plane containing the Earth's magnetic field and the ray direction. The appropriate definitions and formulae are as follows:

Given: D = Magnetic dip angle at the reflexion point (angle of Earth's magnetic field relative to the horizontal). (-90° to $+90^\circ$, positive to the north of the magnetic equator.)

ϕ_m = Magnetic bearing of transmitter relative to observing receiver, measured east of north. (0° to 360° or -180° to $+180^\circ$.)

θ = Ionospheric angle of incidence (angle of downcoming ray-direction relative to the vertical at the reflexion point). (0° to 90°.)

To find: θ_m = Angle between the downcoming ray-direction and the Earth's magnetic field. (0° to 180°.)

ψ = Orientation of the ellipse of the electric field polarization expressed as the rotation about the ray-direction from a position in which the minor axis is horizontal. Looking downwards along the ray-direction, this rotation is anticlockwise if ψ is positive and clockwise if ψ is negative. (-90° to $+90^\circ$.)

Formulae:

$$\cos\theta_m = \cos\theta \sin D - \sin\theta \cos D \cos\phi_m$$

$$\sin|\psi|^* = \frac{|\sin\phi_m| \cos D}{\sin\theta_m}$$

5.2. Axial Ratio of Polarization Ellipse

The axial ratio depends on frequency and the angle θ_m defined above.

Given: f = operating frequency

f_y = gyro-magnetic frequency at reflexion point

To find: R = axial ratio of ellipse (-1 to $+1$)

*This formula does not give the sign of ψ; if this is required and is not apparent from the geometrical configuration, the following alternative formula may be used.

$$\cot\psi = \tan D \operatorname{cosec}\phi_m \sin\theta + \cot\phi_m \cos\theta$$

Formula: $R = \tan \omega/2$

where $\cot \omega = f_y \sin \theta_m \tan \theta_m/2f$ (ω in the range -90° to $+90^\circ$).

Note that if $90^\circ < \theta_m \leqslant 180^\circ$, the values of ω and R are negative. A positive value means that the sense of polarization is anticlockwise looking down the ray, while a negative value means that the sense is clockwise.

5.3. Component of Electric Field in the Vertical Plane

$$F = \frac{\text{Power in electric field in vertical plane}}{\text{Total power in downcoming wave}} = \frac{R^2 \sin^2 \psi + \cos^2 \psi}{R^2 + 1}$$

where the ellipse parameters R and ψ are defined above. The coupling factor F determines the power available in a vertical aerial from an elliptically polarized downcoming wave as compared with the power that would be available in the same aerial from a wave of equal power linearly polarized with the electric field in a vertical plane.

5.4. Total Loss for a Path

With two vertically-polarized aerials there will be a power coupling loss at the transmitting end (factor F_1) as well as at the receiving end (factor F_2). The value of the factor at the transmitting end will be equal to that calculated by the formulae given above on the assumption that the transmitting aerial is used for reception of a signal coming down along the propagation path of interest. Since the value of ϕ_m is changed by 180° in applying the formulae, the value of F_1 will, in general, differ from that of F_2. The product of the two factors $F_1 F_2$ gives the ordinary-wave power transmission factor between vertical aerials compared with the case of a perfectly-conducting sheet at the reflexion point.

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